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INDUCTION HEATING OF A VARYING DIAMETER PREFORM

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13. ABSTRACT *(Maximum 200 words)*
A proposal to use a varying diameter preform for forging the 120-mm M256 gun tube required a modification to the induction heating system power control to provide uniform heating of the preform. In addition, there was a need to automate the heating process for more uniform and consistent heating of constant diameter preforms. Various approaches to modify the control were investigated. A temperature feedback control, determined to be the best type, uses an infrared temperature sensor at the induction coil that sends a signal to a proportional controller. The proportional controller varies power to the induction coil based on the temperature sensed. When the preform reaches the set point temperature, the controller provides just enough power to hold the preform at temperature. Operation of the feedback control has proved successful. It also provides emergency power shutoff if the infrared instrument detects a preform temperature that exceeds a preset limit.

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INTRODUCTION

A proposal to use a preform with a varying outside diameter for forging the 120-mm M256 gun tube resulted in the need to effectively heat the preform. As a result, a project was proposed to modify the control on the Cheston Induction Preheat System. In addition, there was a need to automate the existing manual power control. An automated controller produces an improved quality product by making the process more repeatable and more uniform in temperature.

The existing power control uses electronic circuitry designed to maintain a constant power to the induction coil based on a setting made by the operator via a potentiometer. Separate potentiometers are used for the two timers. The system operates at the power level setting of the first potentiometer until the first time period expires and at the power level setting of the second potentiometer until the second time period expires. The heating cycle presently used operates at a high power level (800 KW) under control of the first timer and then at a lower power level (400 KW) under control of the second timer. Generally, before the second timer expires, the preform reaches the desired forging temperature (1900° to 1950°F). At that time, the operator must lower the power level setting to prevent overheating of the preform. The operator knows the temperature of the preform by the digital readout from two infrared temperature instruments that monitor the preform temperature through windows located on each side of the induction coil (see Figure 1). To maintain the preform at the forging temperature, the operator must monitor the digital temperature readout and adjust the power level setting based on the increasing or decreasing preform temperature. This results in an imprecise control of temperature and strain on the operator who monitors preform temperatures for up to four induction lines. Figure 2 traces the power and temperature under manual

control. Note the corrections in the power level made by the operator and the resulting change in temperature of the preform.

PROCEDURE

To determine the best method of automating the power control, instrumentation was temporarily installed to record data on certain critical parameters associated with the power control. Included were the three-phase current, coil voltage (V), coil volt-amps (KVA), coil power (KW), coil reactive power (KVAR), coil current, coil power factor (PF), and frequency of coil power supply.

An electric power analyzer capable of recording voltage, power, power factor, volt-amps, current, and reactive power in digital form was connected directly across the induction coil for line one of the system. An oscilloscope was used to display the waveform of the voltage from the power supply. The three-phase current was recorded by a separate strip chart recorder through current transformers placed on the three-phase bus at the main line contactor.

Records of the three-phase supply current showed a slight imbalance of the three phases with a maximum difference of about 180 amps. Table I shows the values obtained for the induction coil during operation below and above the Curie temperature (1450°F). The dramatic change in impedance of the coil-workpiece combination above the Curie temperature is demonstrated by the increase in voltage, current, volt-amps, and reactive power and the large decrease in power factor at a constant coil power.

TABLE I. 17-INCH DIAMETER COIL DATA

Below Curie	Above Curie
618 V	738 V
2532 amps	4310 amps
1566 KVA	3180 KVA
801.4 KW	812 KW
1345 KVAR	3075 KVAR
0.51 PF	0.26 PF

Three different approaches to automating the power control were considered. The first was to use a method to sense the diameter of the preform and then to incorporate this information into a microprocessor that would adjust the power based on the preform diameter. One method considered was to establish a relationship between one of the parameters measured with the instrumentation as described above and the preform diameter. After some study, it was apparent that no reliable and repeatable correlation could be established. Despite a general change in power factor and voltage that occurred as the preform diameter changed, the relationship between the diameter and one of the measured parameters was not obvious. As a result, a sensor located at the induction coil to sense the preform diameter was considered. An investigation of various sensor types revealed a problem using a sensor in the high temperature environment around the induction coil. As a result, this was not considered a feasible approach to the problem.

A second method considered was to use a microprocessor to control power. A heating cycle for each preform configuration would be arrived at empirically and then incorporated into the microprocessor. The drawback with this approach was that the power required to hold the preform at the forging temperature was a

variable dependent on the temperature of the coil line and the ambient temperature. Incorporating sensors to monitor these temperatures and feed this information into the microprocessor requires extensive experimental work for a dependable system.

A third method considered was to use a temperature feedback approach. This approach would use an infrared sensor located at the induction coil (see Figure 1) that could monitor the preform temperature through a window located between turns of the induction coil. The temperature of the preform at the point where heating occurred could be monitored. In addition, unintentional melting of the preform* could be avoided by using a relay to shut off power to the coil if the preform temperature exceeds a preset value. For power control purposes, the temperature signal would be sent to a proportional controller, which, in turn, would send a signal to the existing induction coil power control. Based on the temperature sensed by the infrared sensor, the proportional controller would vary induction coil power, ultimately allowing just enough power to hold the preform at the forging temperature. However, several problems were possible with this approach to controlling coil power. These problems include the following:

1. Standard proportional controllers are designed for heating a stationary load. The parameters used with a three-mode proportional controller, such as rate time, reset rate, load demand, and proportional band, apply to a stationary load. The Cheston Induction System oscillates the preform (load) through a two-foot long induction coil via rollers (see Figure 1). It was unknown if the controller would operate properly with a moving load.

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*This is a long-standing problem with the system that occurs when preform motion stops due to mechanical or electrical failure, while power to the coil is still present.

2. The question of stability is always a concern with any type of feedback system. Although mathematical methods are available to determine the stability of a system, these methods require correct values for certain system parameters, which were unavailable. Therefore, experimentation was the only means to determine system stability.

3. The use of an infrared sensor sighted through a small window in the coil left the system vulnerable to failure if the sensor became misaligned or if the view through the window became obstructed. In either event, the controller would probably sense the temperature of the preform as less than the true temperature, resulting in overheating of the preform.

4. A temperature feedback system would base the power level on the surface temperature of the preform. This would not take into consideration temperature gradients through the wall of the preform, which would affect the overall preform temperature.

An experiment conducted as part of another project, which was to evaluate the induction heating for heat treating gun tubes, helped determine if a temperature feedback system would be successful. For this experiment, a 1/4-inch diameter hole was drilled through the induction coil refractory and between two of the coil turns. This provided a port for an infrared sensor to "see" the preform while it was in the induction coil.

An Ircon three-mode proportional controller was used to control power to the coil. The workpiece used was a section of a 105-mm M68 gun tube (Figure 3) with thermocouples inserted at the indicated locations. The temperatures obtained at the end of the heating cycle are given in Figure 3. The coil used for this test proved too large for the workpiece. As a result, it was unable to obtain sufficient power to raise the workpiece above the Curie temperature or to

increase the power on the breech end of the tube, which required more power than at the muzzle end. Thus, the temperature uniformity obtained with this test proved inconclusive for evaluating a feedback control. However, three of the four previously mentioned potential problems were eliminated:

1. Maintaining sensor alignment did not prove to be a problem.

2. The system did not become unstable.

3. The control parameters functioned correctly despite being used with a moving workpiece.

As a result, a decision was made to use temperature feedback to automate the power control.

RESULTS AND DISCUSSION

A specification was prepared to modify the existing power control on one of the four induction preheat lines. This included an emissivity-independent infrared temperature instrument capable of sensing preform temperature through a window in a 17-inch diameter coil. The system was to include a three-mode temperature controller with a recorder capable of recording induction coil power and preform temperature. The system was to have features that automatically disconnect power if the preform is over temperature and a two-position switch for operation in either automatic or manual control (see Figures 4 and 5).

A contract was awarded to Inductoheat Corp.* (formerly Cheston Co., manufacturer of the induction heating system) to modify the power control. Initial testing of the controller indicated a problem with the induction coil window. Rapid and continuous accumulation of water on the window, due to condensation of

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*Inductoheat Corp., 32251 N. Avis Drive, Madison Heights, MI 48071.

water vapor created by the hot environment, obstructed the view of the infrared sensor. The window was redesigned so that it was removable for cleaning and had vent holes for the water vapor to release (see Figure 6). Initial testing of the new window design proved successful. However, attempts to heat a preform revealed a problem with the interface between the proportional controller and the existing power control. The proportional controller requires an interface to an ungrounded circuit, and since the existing power control was grounded, the signal from the controller was not the correct value to function as required. An electronic circuit was designed to produce a grounded output voltage from a floating input voltage. This circuit eliminated the interface problem that existed between the proportional controller and the power control.

Further tests were conducted in order to refine and optimize settings on the controller. The settings arrived at were as follows:

• A proportional band ± 180°F of set point. This means the controller would operate at maximum output until a temperature 180 degrees below the set point was reached. At that point, the controller output would decrease proportionally until the set point was reached.

• Load demand was set at 25 percent of the maximum output. The load demand setting is the output of the controller at the set point temperature.

• Reset rate was 1.0 reset per minute, i.e., the controller would recalculate the load demand required once every minute. Since the setting is an estimate of the required output, and therefore can result in the controller holding the preform temperature below the required set point (a condition known as "droop"), a three-mode proportional controller (currently used) incorporates a reset rate setting. This setting determines how often the controller recalculates where the final holding temperature will be and then compares it to the

desired set point. It then corrects the load demand setting so that the controller ultimately holds the temperature at the correct set point.

• The rate time setting for the three-point controller was not used for this application since it is a feature used primarily for applications where the load temperature increases quite rapidly and is used to prevent severe overshoot of the set point. This particular application did not involve heating at a rate rapid enough to require the rate time feature.

• A set point of 1906°F was used to correlate with readings from the existing Ircon instruments.

• The peak-picker feature, which provides an adjustable decay rate, was set at 0.1 percent of instrument span (1200°F) per second, i.e., the temperature decays 1.2°F per second. This feature provides a damping effect so that the controller output does not swing wildly when the infrared sensor is sighted on a patch of scale or on the ends of the preform (which, because of rapid radiation losses, are at a lower temperature than the remainder of the preform).

Figure 7 is a record of the power and temperature as the preform was heated under control of the temperature feedback system. The oscillating temperature output results from the fact that the preform only has a two-foot section in the coil at any given time. As a result, the portion of the preform out of the coil begins to drop in temperature until it again enters the coil. The oscillation is then a characteristic of the oscillating heating procedure and is not caused by the controller. It can be seen from Figure 7 that once the set point is reached, the temperature at a given point on the preform is quite stable. Compare this result with that of Figure 2 where, while under manual power control, the temperature of the preform rises and falls as the operator attempts to maintain the preform at the forging temperature by adjusting the power level.

CONCLUSION

This project successfully demonstated that a closed-loop temperature feedback control can be applied to an oscillating-type induction heating system. In addition, it provides automatic power control for the Cheston Induction Preheat System for line one when using a 17-inch diameter coil. This alleviates the operator from continually monitoring preform temperature. Furthermore, this control has the added feature of providing power shutoff whenever an overtemperature condition occurs. Thus, the problem of inadvertent melting of preforms during a mechanical or electrical breakdown is avoided.

The use of automatic power control via a temperature feedback circuit is a significant improvement in temperature unformity versus manual power control. Not only can the final preform temperature be held within a much tighter band, but the uniformity of temperature along the length of the preform is improved. Once the forging temperature is reached, variations in temperature as large as 60°F are noted while in manual control. While in automatic control, the system is able to hold the temperature within ± 10°F.

The lessons learned from the development of the feedback system and the experience gained through its continued use should be beneficial in the development of the new induction system (scheduled to be operational within the next two years). This system will use temperature feedback as a means of power control for each of the induction heating lines.

Figure 1. Induction coil.

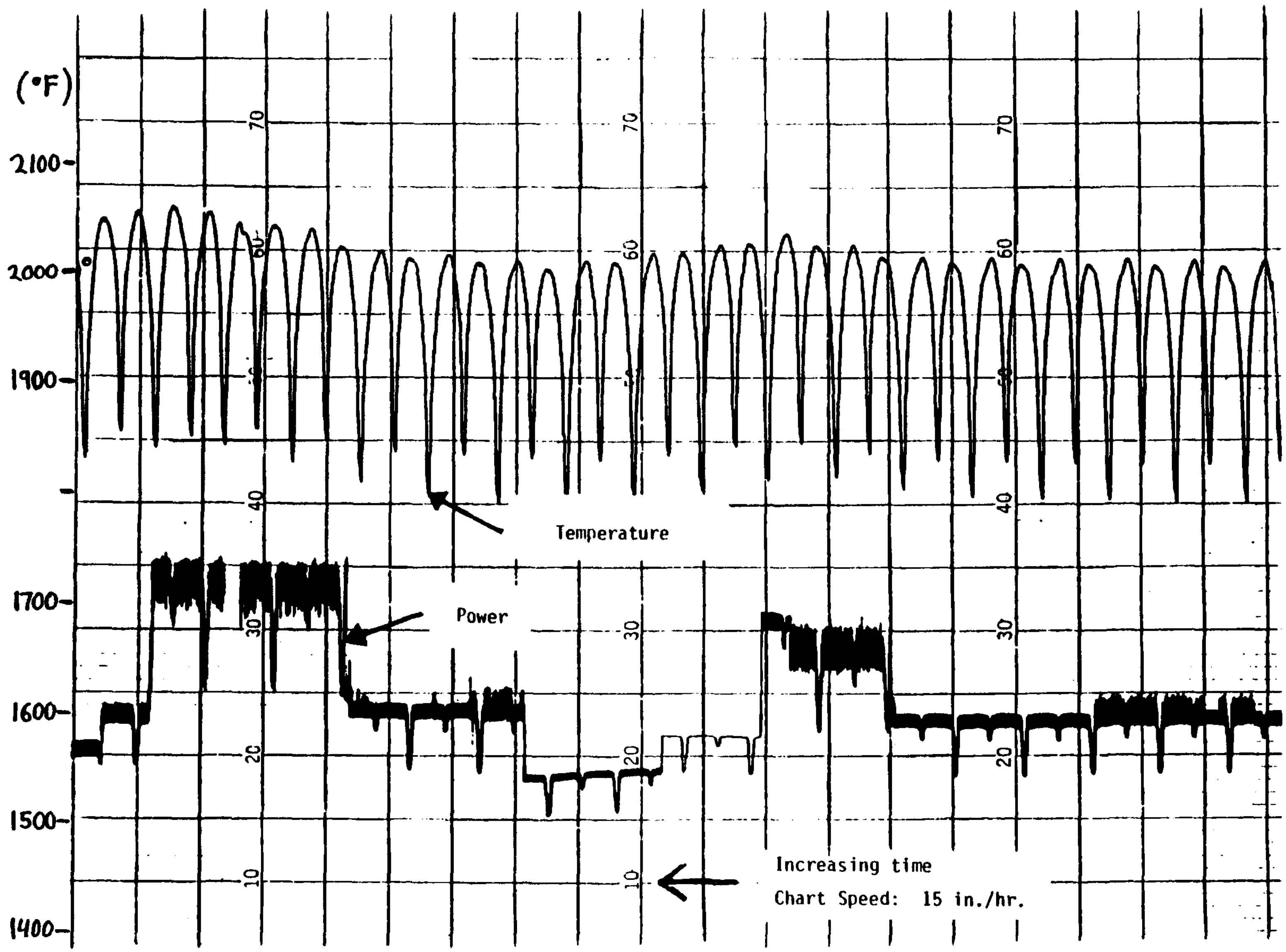

Figure 2. Manual power control.

T - Top I - Inside
B - Bottom O - Outside

T.C.#	Inches from Breech End	Position	Temperature (°F)
(0	1	B I	1252
(3	1	T O	1287
(4	52	B I	1378
(5	52	B O	1374
(6	52	T I	1372
(7	52	T O	1355
(8	76	B I	1443
(10	76	T I	1441
(11	76	T O	1404
(12	100	B I	1458
(13	100	B O	1444
(14	100	T I	1448
(15	100	T O	1421
(16	179	B I	1321
(17	179	B O	1323
(18	179	T I	1327

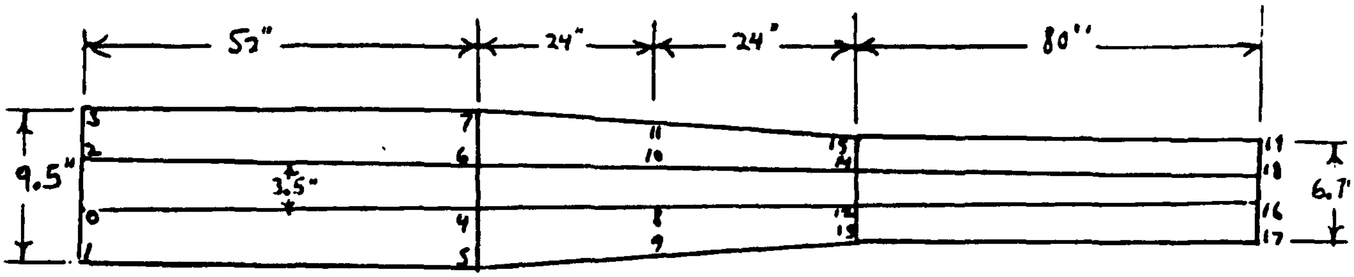

Figure 3. 105-mm M68 tube section instrumented with thermocouples.

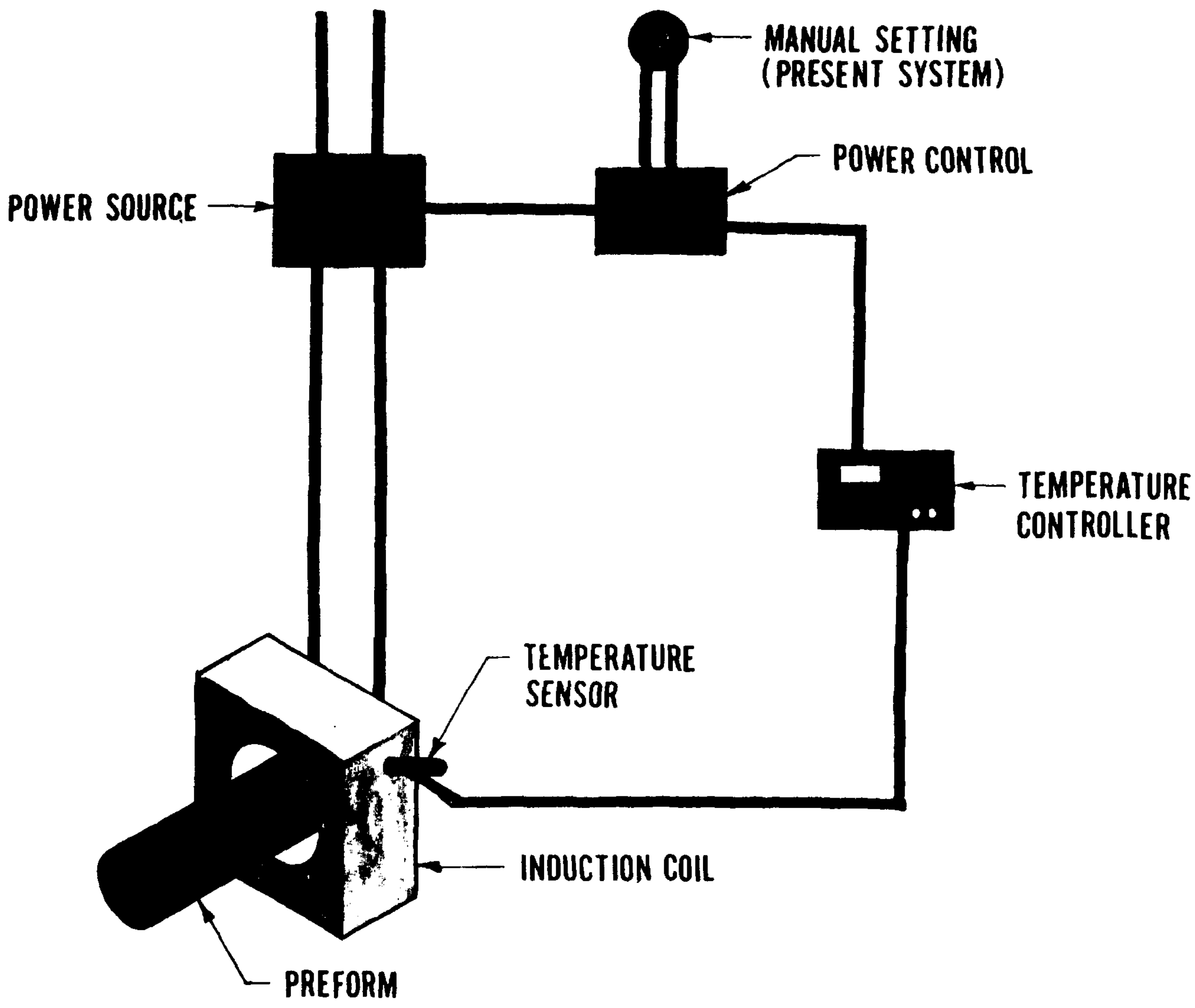

Figure 4. Block diagram of temperature feedback system.

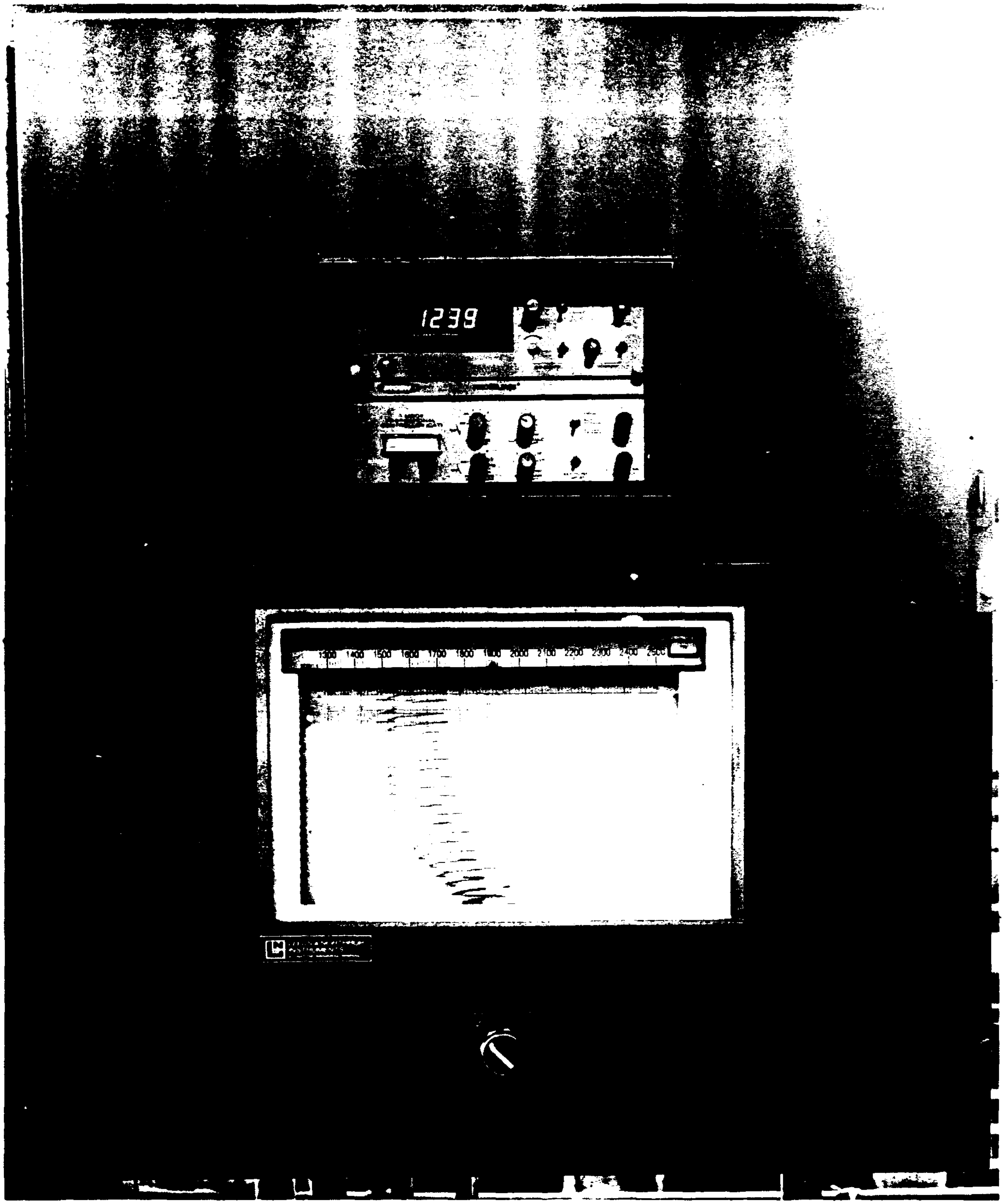

Figure 5. Temperature feedback power controller (top) and temperature and power recorder (bottom).

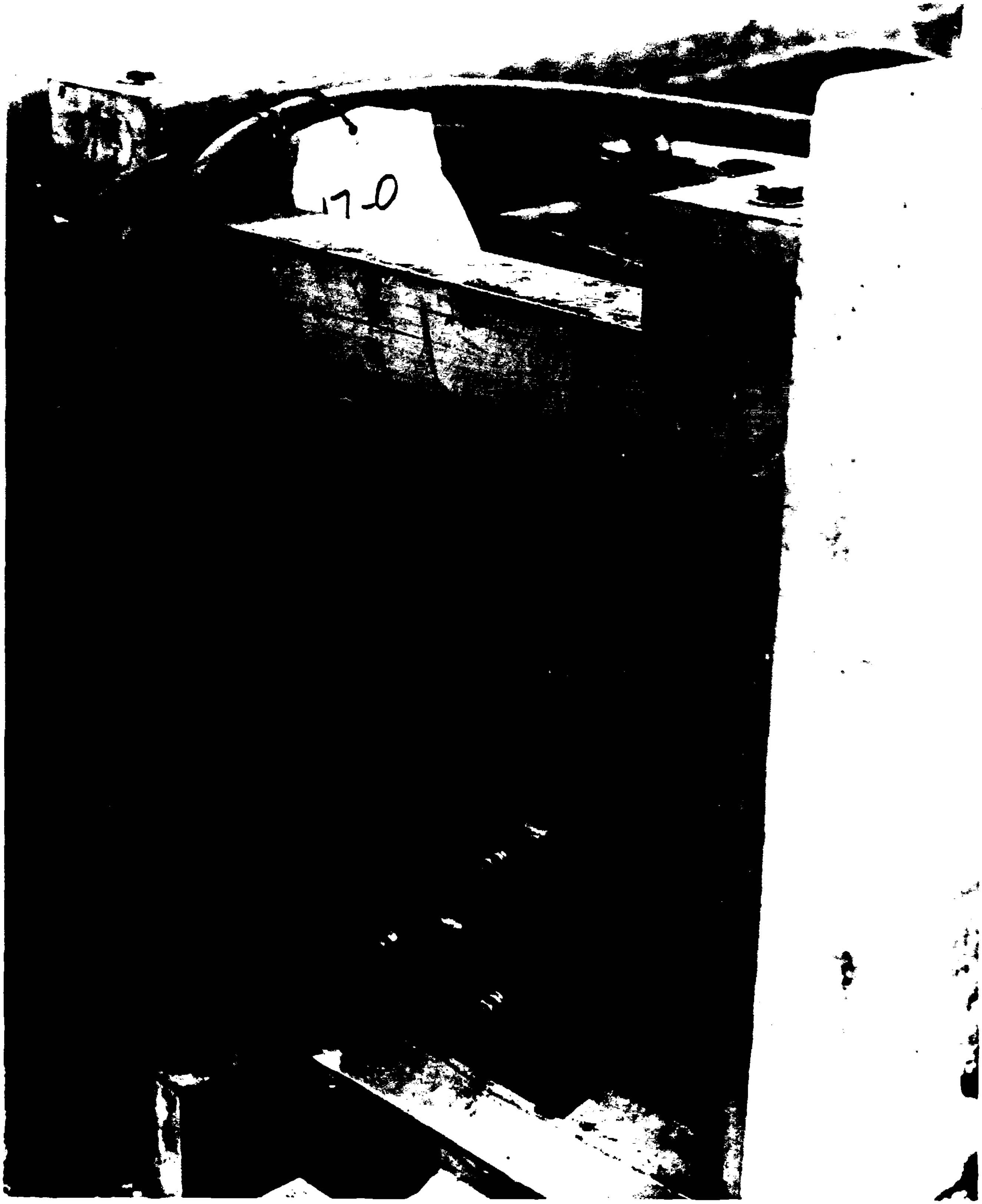

Figure 6. Induction coil window.

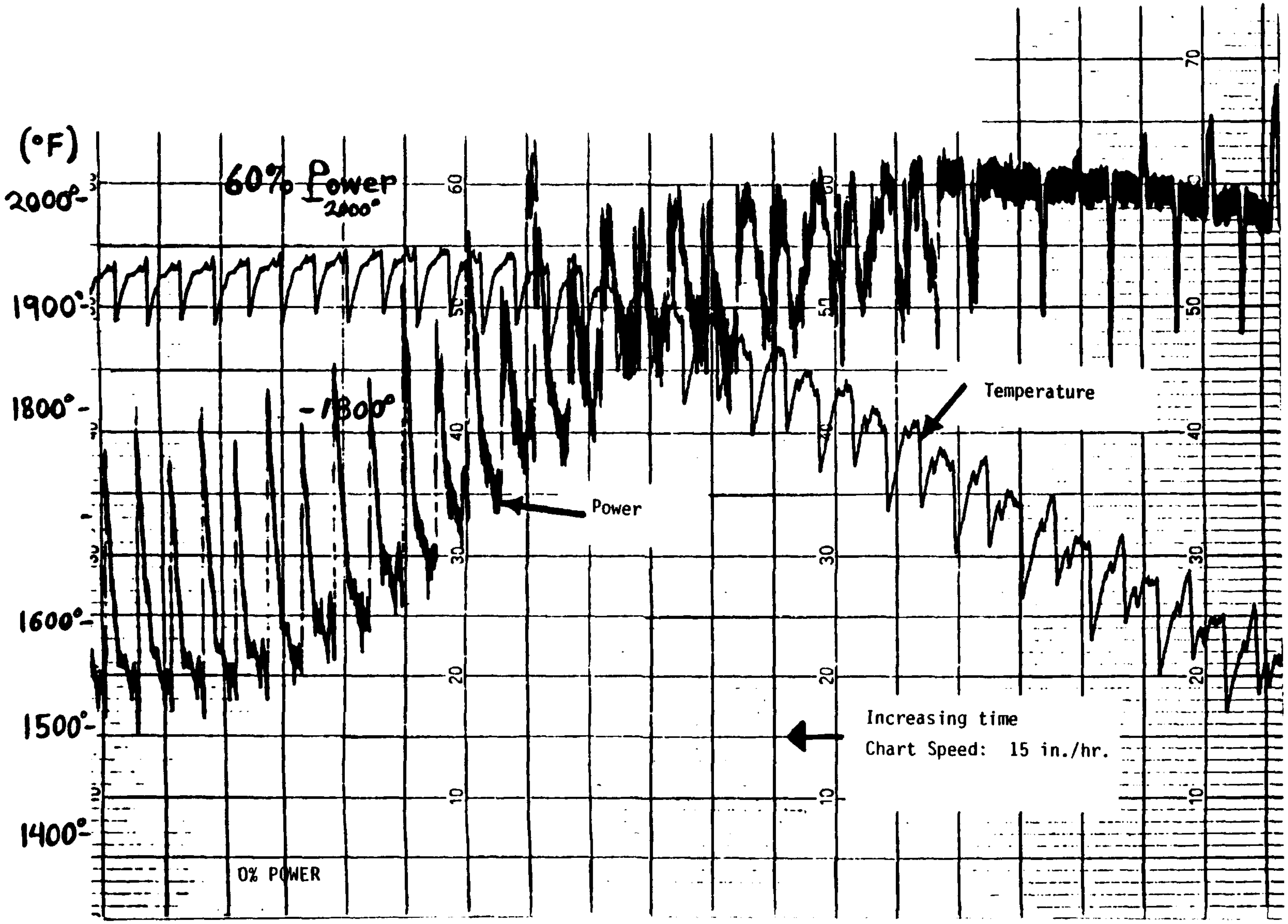

Figure 7. Automatic power control.

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